1 The World is at the Eve of a New S&T Revolution

The modernization process is, in essence, the history of S&T progress and innovation. Every change in modern society correlates closely with the transformative breakthroughs in science and technology. A S&T revolution is always driven by the tremendous demands from modernization, and is the consequence of innovation and breakthroughs in knowledge and technology.

1.1 Modernization Calls for a New S&T Revolution

Modernization originated from the West Europe some 250 years ago and then spread unceasingly around the world. The Renaissance, Enlightenment Movement, and Science Revolution catalyzed European industrial revolution, political revolution and religious reform, and, accordingly, initiated the process of industrialization and modernization.

In the history of modernization, two important science revolutions gave rise to the revolution in epistemology, led to the reforms in man's outlook on world, values and development, and provided knowledge backing for technology revolution.

The first science revolution started in the fields of astrology, physics, and physiology during the 16th and 17th century. N. Copernicus' *De Revolutionibus Orbium Coelestium* (*the Celestial Movement*) smashed man's infinitive trust on the capacity of sense organ, Galileo Galilei's creative research changed the empirical science into the experimental science, and Isaac Newton's *Philosophiae Naturalis Principia Mathematica* (*The Mathematical Principles of Natural Philosophy*) shed light on the laws governing the motions of terrestrial bodies and celestial bodies, and their identities, all of which freed natural sciences from theology and thus established a new world outlook on mechanics completely different from the old. The Calculus set up by Isaac Newton and Leibniz provided scientific backing for mechanics and other sciences, and thus changed man's mode of thinking. *On the Origin of Species* by Charles Robert Darwin fully described the laws governing the origin and evolution of species, which broadened man's knowledge on competition and development, and even

became important ideological base for future social changes. And the classic electromagnetism theory set the scientific base for electric revolution.

The basic structure of modern science system was jointly set up, in the early 20^{th} century, by the revolution in physics represented by quantum mechanics and theory of relativity, and the major science events such as Big Bang Theory, the Double-helical Structure of DNA, Plate Tectonics Theory and computing science. This revolution in modern science cast light on the basic laws governing the micro material world, described the interrelations among time, space, matter and energy, advanced a new outlook on time and space, and demonstrated the great power of science in productivity development, which helped shape man's modern life and had a far-reaching impact on its future life. Taking this opportunity, developed countries took the lead in stepping into the knowledge-based economy. Hence began a new round of modernization drive in human history.

In the modernization process, the technology revolutions and industrial revolutions reinforced each other, resulting in a leap-frog advance in productivity and abundance of material wealth and causing extensive changes in economy, society and military force, thus becoming the engine to man's modernization drive.

The discovery of steam engine in Europe and its extensive application in the mid-18^{th} century marked the first technology revolution, which broke the limit of natural motive power and reached to large-scale production and mechanization. The first industrial revolution broke out in the UK with the advancement of technology revolution. The machine-equipped industry gradually developed into five industrial systems from textile to excavating, metallurgical, machine manufacturing and transporting industries, making the UK into the first industrial power in the world. The European continent and the USA followed up to launch their industrialization drive in the first half of the 19^{th} century, with France, Germany and the USA being the fastest in development and largest in scale. The first industrial revolution completely smashed the old relations of production and changed the world structure. Hence began the era of industrial civilization of mankind.

The advent of electric power technology marked the second technology revolution, in the 1830s, by advancing human society from steam to electric age. Internal combustion engine and motor engine gradually replaced the steam engine. Heavy industries such as electric power, oil and chemical industry rose very rapidly. The advancement of productivity caused the formation of industry structure featured by huge consumption of natural resources and fossil fuels as well. Germany and the USA emerged as new industry powers and gradually broke the monopoly of the UK. These big powers competed in the world market to pursue or even plunder natural resources, causing frequent warfare around the world.

The advent of electronic technology, space and aeronautic technology, nuclear technology, information and the Internet technology, since the

1940s, has marked the third technology revolution, bringing mankind into the electronic age from the electric age. The rapidly developing electronic industry gave rise to many emerging industries, promoted the upgrading of conventional industry and the development of military and related industries. The industrial productivity increased tremendously, with the 20 years' world gross industrial output value from 1953 to 1973 almost totaling that of the previous years. The major capitalized countries such as the USA, Germany, France and the UK stepped into a period of matured industrialization. Since the 1970s, the extensive use of information technology and digital networking has given impetus to the development of modern service industry, greatly changed man's way of life and mode of production as well, speeded up the globalization, and advanced human society into information age. The rapid development of biotechnology has brought out the progress in medicine, health and agriculture industry.

Looking into the future of modernization, man's strong desire for modern life will rise in sharp conflict with the affordability of natural resources and eco-environment as well, which will be, to a larger extend, determine the direction, scale and progress of human modernization.

In the next 50 years, more than 2–3 billion people, including Chinese and Indian, will strive for modernization, and a majority of developing countries will dedicate themselves to industrialization. Over 200 years' industrialization in human history has brought less than 1 billion people into modernization, but with the severe exhaustion of natural resources and fossil fuels, and at the great sacrifice of natural environment. We can no longer boost our economy with the conventional mode of plundering non-renewable natural resources and centering the world resources only on a few big powers. Instead, we are in urgent need to develop new resources, sort out new development mode and way-outs, and set up new mode of production and lifestyle. This need strongly calls for transformative breakthroughs in science and technology, and the benefits of science and technology for a majority of people. Human civilization requires a new round of S&T revolution and industrial revolution as well.

Science and technology is by nature revolutionary, so far as its laws of development is concerned. Both science revolution and technology revolution take place unexpectedly as a consequence of knowledge explosion, and goes through cycles in revolution.

A science revolution comes out of the fundamental conflicts between the existing theories and scientific observation and experiments and, thus, causes a leap in scientific thinking. It appears in the form of a new system of scientific theories. Since the second half of the 20^{th} century, the knowledge explosion has just helped to optimize the existing science theories, but not given rise to any breakthroughs or discoveries which can be placed on a par with the theory of relativity and the like in the first half of the 20^{th} century. "The Silence of Science" has remained for over 60 years and, in the meantime, the inner contradiction within the knowledge system of science and technology comes into being.

Technology revolution causes a leap in man's way of living and development. It comes out of the practical experience of mankind and the creative application of scientific theories, leads to innovation in major equipments and methods, and results in substantial enhancement of man's capability and efficiency. Technology revolution goes through in cycles and is likely to occur every one century. It has been 80 years since the third technology revolution broke out in the 1930s and the 1940s, during which major technology innovation occurred one after another, and the time span for the transfer of key technology discoveries into industrial production shortens. Since the 1970s, the cycle of technology transfer became even shorter. And in the field of information technology, technology transfer occurs once every a few months.

In conclusion, the world is at the eve of a transformative S&T revolution, which may likely to happen in the first half of the 21^{st} century. The big change in world economic structure caused by the current global financial crisis will speed up the advent of another round of S&T revolution.

The First Science Revolution

The first science revolution took place in the period from the middle of the 16^{th} century to the end of the 17^{th} century. Before that, Aristotelian tradition had, for long time, been a basis of knowledge shared by Western scholars. The natural philosophy in his *Physics, Problemata Mechanica*, and *De Caelo as well* as the subsequent geocentric theory, developed by Claudius Ptolemy, dominated the theoretical illumination about mechanics and cosmology. Till the 16^{th} and 17^{th} centuries, Aristotelian tradition was seriously challenged with practical and theoretical research. In 1543, after a few years' hesitation, N. Copernicus finally published, right before his death, the *De Revolutionibus Orbium Coelestium* (*the Celestial Movement*) and his new model of revolutions of planets, which overturned Ptolemy's geocentric theory. In the same year, Andreas Vesalius published a famous book on anatomy, *De Humani Corporis Fabrica* (*the Structure of the Human Body*), to correct the wrong explanation of the circulation of blood given by Galen, a doctor in ancient Rome.

The mechanical researches done by Galileo Galilei and Isaac Newton were masterstrokes in the first science revolution. The problems in the movement of projectile and single pendulum, the stability of buildings as well as the movement of planets in practice were sharply contradictory to the explanations in Aristotelian tradition and became challenging research objects. Galileo Galilei, an Italian, developed experimental research methods and combined experimental methods with mathematical ones. He creatively discovered movement laws of single pendulum, a falling body and projectile. In 1609, he made astronomic observation with a telescope for the first time. Based on the accurate record of observation made by Tycho Brahe, Johannes Kepler brought forward a new law of movement of planets. It was a sheer coincidence that Isaac Newton was born in the same year of 1642 when Galileo died. Newton summarized the law of motion and the law

of gravity, and integrated the theories of classical mechanics *in The Mathematical Principles of Natural Philosophy* published in 1687, which set up a reliable basic structure for modern science.

The first science revolution resulted in transformative development of main disciplines in the period from the 17th to the 19th centuries, and established an integrative system of modern science.

- In the 17th century, Descartes founded analytic geometry, while Newton and Leibniz established calculus. Henceforth, analysis became the mainstream of mathematics, in which many branches were established, but it was not yet precise in theory. Till the 19th century, mathematical analysis gradually became a precise logical system. For examples: A. L. Cauchy, a French mathematician, rigorously defined the continuum of a function, differential coefficient and integral with limit; K. Weierstrass, a German mathematician, set up a strict basis for mathematical analysis; G. F. B. Riemann, a German mathematician, contributed quite a lot to mathematics with his research in the fields of algebraic function theory, differential geometry, analytic number theory and potential theory; G. Cantor, a German mathematician, established set theory for mathematical analysis; E. Galois and others set up group theory; Leman further developed non-Euclidean geometry while D. Hilbert, a German mathematician, improved methods of axiom.

- While classical mechanics kept being improved, there were important breakthroughs in the fields of optics, thermodynamics and electromagnetic in physics. Robert Hooke and Christiaan Huygens respectively proposed a wave theory of light, which was proved with experiment done by Jean Foucault, a French physicist. Thomas Young, an English polymath, discovered interference law of light, which was proved with mathematics by Augustin-Jean Fresnel, a French engineer. By studying efficiency of steam engine, Nicolas Léonard Sadi Carnot, a French physicist, proposed principles of heat engine. By inventing voltaic pile and battery, Alessandro Volta approached to the world of electricity with a big step. Electrical current magnetic effect discovered by Hans Christian Oersted, the Ampere law discovered by Andre Marie Ampere, and the law of electromagnetic induction discovered by Michael Faraday, an English chemist and physicist, formed the basis of the invention of electrical machinery. James Clerk Maxwell, a Scottish theoretical physicist and mathematician, summarized all electromagnetic phenomena with a group of mathematical equations. His predictions of the existence of electromagnetic wave and that electromagnetic wave spread with velocity of light were proved with experiment by Heinrich Rudolf Hertz, a German physicist. Thus, electricity, magnetism and optics were connected together. More than ten European scientists, including Julius Robert Mayer, respectively discovered principle of conversation of energy, which revealed integrity of various sorts of movement among heat, mechanics, electricity and chemistry and made physics unparalleled integrality.

- Chemistry broke away from alchemy in the 18th century and stepped into an age of real scientific research, resulting in a revolution. Antoine-Laurent de Lavoisier found, through experiments, that burning was, in fact, oxidation, so that new burning theory replaced phlogiston theory. In 1789 when French Revolution took place, Lavoisier published his book, *Traité Élémentaire de Chimie* (*Elementary Treatise on Chemistry*), in which the table of the 33 elements were divided into four groups. In

1803, Dalton, an English chemist, meteorologist and physicist, proposed chemical atomism, in which he clarified the conceptions of element, elementary substance and compound with atom. This gave a theoretical explanation to experiential chemical laws. In 1811, A. Avogadro, an Italian physician, brought about concept of molecule which was finally accepted by chemists after half a century disputes. The theories of atom and molecule established theoretical basis for chemistry and blazed a way for construction theory of organic compound, and the development of organic analysis and organic synthesis. Dmitri Ivanovich Mendeleyev, a Russian chemist, and J. L. Meyer, a German chemist, respectively brought forward the periodic table of the elements in 1869, which guided the study of elements, and searching for new elements and new materials as well.

- The microscope invented in the 17th century was a good tool to understand the microworld. Marcello Malpighi, Robert Hooke and Antonie van Leeuwenhoek made use of microscope to observe cells, and animalcules. Based on the work of Carl von Linné, a Swedish botanist, physician and zoologist, biological taxonomy was established in the 18th century. Biology developed into an integral discipline in the 19th century, in which the most important achievement was evolutionism. J. B. de Lamarck, a French botanist and invertebrate zoologist, was the first person who put forth the theory of biological evolution. After half a century, Charles Robert Darwin, a British scientist, clarified biological evolutionism systematically *in The Origin of Species* published in 1859. Based on experimental research of biology, A. Weismann, a German zoologist, developed Darwin's theory. In the 19th century, another important achievement was cytology. With the development of the technology of microscope and experimental science, scientists made some new achievements by observing cells, based on which M. J. Schleiden, a German physiologist and histologist, and T. Schwann, a German physiologist, put forth the theory of cells in the period from 1838 to 1839.

The first science revolution formed new world outlook and methodology. Science became an independent social organizational system.

Copernicus and Galileo established new scientific theories, which were contradictory to religious credenda which predominated during that period. Christianity, the then paramount authority, was challenged so that the church was very sensitive to any challenges to Aristotle's tradition. In 1600, Giordano Bruno was burned to death because he championed Copernicus' theory. In 1633, prestigious Galileo was tried by the church and was sentenced to imprisonment for life. However, science couldn't stop developing in spite of the church's opposition. Darwin's evolutionism beat Genesis and was accepted by a majority of people. It also exerted a far-reaching influence on biology, physiology, social science and religion. During the first science revolution, induction based on experiment that Francis Bacon emphasized and deduction generalized by Rene Descartes formed methodology in science which became popular to this day. The establishment of Florence Science Society in Italy, the Royal Society in Britain, the Royal Academy of Sciences in France, and Berlin Academy of Sciences in Germany symbolized the organizational system of modern science, which evolved into two kinds of national research organizations in science: the British and American tradition, and the European continental tradition. The former was represented by the Royal Society in Britain and the American Academy of Sciences, while the latter was represented

by the French Academy of Sciences, Russian Academy of Sciences, the Kaiser Wilhelm Society in Germany (later named as The Max Planck Society), the Chinese Academy of Sciences, French National Center for Scientific Research, etc.

The Second Science Revolution

The second science revolution was a fundamental transformation in natural science theory at the beginning of the 20th century, mainly represented by the theory of relativity and the quantum theory.

In the end of the 19th century, facing powerful classical physics, people generally thought that only improvement and complement could be made in physics in the future. However, crisis laid dormant in physics during the period. In 1900, Lord Kelvin of Largs, a British scientist, mentioned that there were two dark clouds above the mansion of physics: one was "ultraviolet disaster" in black-body radiation; another was relative to the failure of the aether-drift experiment.

The problem of black-body radiation was a hot topic at the end of the 19th century. In 1896, Wilhelm Wien, a German physicist, deduced hot body energy distribution law. However, the experimental result was quite different from the part of low frequency. In 1900, John W. Rayleigh, a Britain physicist, corrected Wien's hot body energy distribution law, and made the part of low frequency correspond with experimental result. However, there was still warp between high frequency and the result of experiment as the part of high frequency was close to the violet of spectrum. This nonidentity was called "ultraviolet disaster". In December of that year, Max Planck put forth the concept of "quantum" in his lecture delivered in Germany physics society, which was the first thunder in science revolution in the 20th century, and conduced to the quantum theory, the first footstone in modern physics. Its revolutionary character was that it introduced discontinuity of energy into physics, which almost penetrated into all microcosmic fields. In 1905, Einstein brought forward the concept of "photons" and explained the problems of photoemission perfectly. In 1911, Niels Bohr applied quantum theory to theory of atomic model, whose quantum orbit of its hydrogen atom was completely consistent with experimental result. During the period from 1923 to 1924, Louis de Broglie put forward matter wave hypothesis and extended to all material particles. In 1925, with the help of Max Born and P. Jordon, Werner Heisenberg, a German theoretical physicist, established matrix mechanics, which was improved soon by Paul Adrie Maurice Dirac, a Britain theoretical physicist. In 1926, based on the work accomplished by Louis de Broglie, Erwin Schrödinger, an Austrian physicist, established wave mechanics. Before long, he proved that matrix mechanics and wave mechanics were equivalent in mathematics. Quantum mechanics exerted a profound influence on human being's view of nature and greatly promoted the development of atomic physics, solid-state physics and nucleus physics. It was a powerful tool to study the atom, molecule, solid as well as the structure and movement of atomic nucleus, and formed theoretical basis for semiconductor technology and atomic energy technology.

Aether-drift experiment was designed by two American scientists, Albert Michelson and Edward Morley, to prove the existence of aether. Scientists in the 19th century thought that it was luminiferous and full of universe. Results of the highly precise experiment conducted by the two American scientists showed that the velocity of aether was zero, or that velocity of light was a constant. This was completely contradictory to relativity principle in classical physics. In 1905, A. Einstein published *On the Electrodynamics of Moving Bodies* and put forward Special Relativity. With Special Relativity, many amazing results could be obtained. Although they were so absurd, experiments over a hundred years proved that it was correct. Special Relativity thoroughly revealed integrity among movement, time and space. With ten years research onward, Einstein completed General Relativity in 1915, which revealed integrity among four-dimension time and space and substance. The establishment of Relativity formed the other footstone of modern science and let us has new knowledge of the nature of time, space and the universe. In his late years, Einstein concentrated on the study of unified field. Although his efforts were made in vain, he encouraged himself with the words of Gotthold Ephraim Lessing, a Germany writer: “It is not the truth that a man possesses, or believes that he possesses, but the earnest effort which he puts forward to reach the truth, which constitutes the worth of a man.”

In 1929, Edwin P. Hubble, an American astronomer, put forth his famous Hubble’s Law: The velocity of galaxy moved from solar system and the distance between them was direct ratio. Based on General Relativity and Hubble’s Law, modern cosmography rose vigorously, in which the most famous was Big Bang theory put forth by George Gamow in the 1940s. In 1964, Arno Penzias and Robert Woodrow Wilson, American radio astronomers, discovered the cosmic microwave background radiation, which supplied important foundation to Big Bang theory.

In the field of micro-sized particles, James Chadwick, a British physician, discovered neutron in 1932, which didn’t carry electricity but it could be an ideal “bomb” to bombard atomic nucleus. In the same year, P. Anderson, an American physicist, discovered positrons which had been predicted by Paul Dirac. In the 1940s, mesotron was found which was previously predicted by Hideki Yukawa. In the 1950s, neutrino was found predicted by Wolfgang E. Pauli. In the research of weak interaction between elementary particles, Tsung-Dao Lee and Chen-Ning Yang discovered violations of the principle of parity conservation (the quality of space reflection symmetry of subatomic particle interactions) in 1956, which was proved in Chien-Shiung Wu’s experiment soon after. In 1964, Murray Geli-Mann brought forward quark model of hadronic structure. In 1968, Steven Weinberg and Abdus Salam respectively developed the theory of the weak force and electromagnetic interaction, and unified the weak force and electromagnetic interaction.

The 20th century witnessed a rapid development in biology. In 1900, three scientists from different countries coincided in discovering Mendel’s work which had been neglected for 35 years and hence established a new discipline, genetics. Afterward, gene in Mendelian genetic theory found its application in the study of American Morgan School. The discovery of the Double-helical Structure of DNA was the most progressive in biology in the 20th century. The discovery was closely relevant to the development of genetics, cytology and chemistry. There were three scientific research teams engaged in the research of crystal structure of DNA.

However, it was James D. Watson, an American biologist, and Francis Crick, a British physicist, that put forth the Double-helical Structure of DNA at first in 1953. This symbolized the naissance of molecular biology.

Geocentric theory was a dominant view in geology at the end of the 19th century. In 1912, Alfred Lothar Wegener, a German rocksy, proposed the theory of continental drift in 1912 and clarified it systematically in 1915. He thought that the continents and oceans were formed due to their drifting apart from a giant continent in Paleozoic, and supported his theory with evidences. However, there was no reliable explanation of drifting motivity in the theory of continental drift. In the 1960s, Seafloor Spreading Theory further explained the theory of continental drift. Afterward, Plate Tectonics Theory proposed by Xavier Le Pichon, a French geophysicist, supplied a rational explanation to how the continents drifted. The development from Continental Drift Theory to Plate Tectonics Theory was a significant revolution in geological theories.

Mathematical research in the 20th century reflected in the following three aspects: pure mathematics tended to abstraction and unification; applied mathematics developed unprecedentedly; and mathematics was combined with computer science closely. Based on the development of Group Theory in the 19th century, abstract algebra greatly developed in the first half of the 20th century. French Bourbaki school put forth general view of algebraic structures. *Modern Algebra* written in 1931 by Bartel Leendert van der Waerden, a Netherlander mathematician, was the first sample of such a mathematical structure. Boundaries between each branches of mathematics got to blur in the second half of the 20th century. Meanwhile, interaction between mathematics and other fields was gradually strengthened. Therefore, there emerged cross-disciplines, such as mathematical physics, biological mathematics and mathematical economics. Alan Turing's Computability Theory, Boolean Switching Algebra by Claude Elwood Shannon and Architecture for a Computer System by John Von Neumann made the electronic computer come into reality, and established scientific basis for human beings to step into the information era.

The science revolution in the 20th century revealed the natures and laws of micro-sized particles, macro universe and living creatures, caused fundamental changes in world outlook and scientific activities, and resulted in a leap in man's understanding of nature. Moreover, scientific research model was changing. Scientists engaged, more and more, into teamwork, and international cooperation was strengthened. "Mega Science" model was becoming conspicuous. People could feel strongly the revolutionary power of science in human civilization.

The First Technology Revolution

The first technology revolution refers to the fundamental technological innovation which started in the UK in the middle of the 18th century and was interdependent with industrial revolution, mainly represented by the invention and

application of the steam engine as well as machinery work instead of manual labor. This technology revolution mainly reflected in the following five aspects:

Firstly, machines were invented and applied in textile industry. In 1733, J. Kay invented a flying shuttle which doubled the efficiency of a loom. Thereafter, lots of machines and tools were invented and applied in spinning and weaving. In 1764, J. Hargreaves invented Spinning Jenny; in 1768, S. D. Arkwright made a water frame; in 1779, S. Crompton invented his Spinning Mule; and in 1785, E. Cartwright invented a power loom, which increased efficiency in tens of times. With mechanization and technological innovation in textile industry, it became an urgent and technologic need to seek for mechanical power, which could replace natural power, such as animal power, wind power and water power.

Secondly, steam technology was invented and improved. Steam engine was made to drain in mine at first. Till the 17th century, coal became important fuel in Britain and drainage was a main factor to restrict output of coal. In 1698, T. Savery invented a steam driven water pump, Miner's Friend, which was further improved by T. Newcomen, and initially solved the problem of drainage in coal mining. In 1769, J. Watt made a great improvement in Newcomen's steam engine and overcame such shortages as big size, high consumption of coal and low thermal efficiency; and in 1781, Watt invented revolving steam engine. Thereafter, the steam engine became a "universal power machine" rather than a drainage device. It finally turned fuel into power, broke through restriction of natural power and supplied large amounts of power to textile machines.

Thirdly, manufacturing was formed to produce various kinds of machines. At the end of the 18th century, with the establishment of various factories, it was urgent to produce a large number of machine tools for steam engines and textile machines. In 1797, H. Maudslay invented a key device in manufacture, an accurate screw cutting lathes, which directly resulted in large machine processing factories. Hence, a group of outstanding designers of machine tools and manufacturers, such as J. Whitworth, and a series of inventions promoted the development and improvement of modern machine tools. Various kinds of machines and tools were gradually produced, which established the foundation of mechanization in modern industry.

Fourthly, smelting technology of iron and steel developed. The rising of machine manufacturing required more and more iron and steel, which gave rise to the quick development of smelting technology. In 1709, Abraham Darby smelted iron with coke instead of charcoal. Henceforth, smelting of iron got rid of restriction of forest resources. In 1760, John Roebuck improved technology of blast in smelting of iron. During the period from 1783 to 1784, H. Cort invented puddling and shingling processes, with which wrought iron and steel were made. These inventions increased iron output dramatically. There was a breakthrough in smelting of steel, too. In 1740, B. Huntsman used a crucible to make cast steel parts for the first time.

Fifthly, steamship and train were invented. In 1807, Robert Fulton, an American engineer and inventor, invented a ship driven by a steam engine, which resulted in changes in modern transportation by water. The invention of a train was resulted from the steam engine fixed in a vehicle on land. In 1825, G. Stephenson built the first practical rail line, which began an era of railway transportation.

From the end of the 18th century to the beginning of the 19th century, technology of steam engine interacted with the technologies in the fields of coal, mining and smelting, machine manufacture, textile and transportation and formed a brand-new technological system. The wide application of these technologies was the most decisive factor of Industrial Revolution. This technology revolution caused a leap forward in productivity and established a capitalistic mode of production. Hence, the Western Europe stepped into an industrial society.

The Second Technology Revolution

The second technology revolution was a tremendous transformation in the technologies of electricity and electrical apparatus, internal-combustion engines, steel-making, petroleum and new vehicles, which took place in the 1930s and was mainly represented by the technology of electric power and the invention of internal-combustion.

Firstly, electric power and electrical apparatus developed. Based on the achievements of electromagnetic such as the law of electromagnetic induction, scientists and engineers had invented various kinds of electrical machinery. In 1832, H. Pixii invented the first permanent-magnet direct current dynamo. In 1866, W. Siemens invented a self-excited generator, which made it technologically possible to build electrical machinery with big capacity. In 1870, Z. T. Gramme made the first practical direct current dynamo which could really generate continuous current. In 1873, Siemens Company invented drum armature, which made electrical machinery more efficient. In 1879, T. Edison invented vacuum carbon filament lamp, and he made 110-volt self-excited direct current generator in 1880. In 1882, Edison Electric Light Company built the first direct current power plant in New York, in which there were six dynamos. Each dynamo could light 1500 15-Watt bulbs, which symbolized the appearance of the first electrical lighting system for civil use. In order to solve contradictory problems between high voltage in long distance transmission of direct current and low voltage power for civil use, alternating current electrical machinery and transformer were invented one after another. In 1886, N. Tesla made a two-phase electromotor. In 1889, M. von Dolivo-Dobrovolsky, a Russian engineer, invented three-phase squirrel-cage asynchronous motor and three-phase convertor one after another and put forth three-phase system. In 1891, three-phase alternator, three-phase asynchronism motor and transformer were put into service. This symbolized a new stage of the development of electrical machinery. With innovation in the way to supply power, electrical technology quickly spread. Therefore, a series of brand-new technological fields formed, such as, electro analysis, electroplating, galvanothermy, electro smelting, electroacoustics, and electrical lamp-house. This resulted in a technological system with technology of electric power as its core.

With the development of electrical technology, the technologies of telegraph, telephone, radio and television came out one by one. In 1836, S. F. B. Morse, an American inventor, made the earliest wire telegraph in the world. In 1876, A. G.

Bell, an American inventor, invented telephone. In 1896, M. G. Marconi, an Italian, invented radio. Five years later, Marconi succeeded in sending aerogram across the Atlantic Ocean. In 1904, J. A. Fleming, an English electrical engineer and physicist, invented electronic vacuum diode while, in 1907, an American inventor, L. de Forest, invented electronic vacuum dynatron which solved the problem of electronic signal amplification. In 1916, an American, Frank Conrad, built a radio station. Till 1930, there was a global radiobroadcast system. Such parts as photoelectrical kinescope, magnetron, klystron and travelling-wave tube were invented one after another, which laid the foundation of television, radar and microwave corresponding.

Secondly, internal-combustion engine was invented and applied. In 1862, Alphonse Beau de Rochas, a French engineer, put forward the theory of operating cycle to make an internal-combustion engine with high efficiency, which laid a theoretical foundation for the development of internal-combustion engine. In 1876, Nicolans August Otto, a German inventor, made a four-separate-stroke gas engine, which was as significant as the steam engine improved by Watt. In 1883, Gottlieb Daimler, a German engineer, made the first gasoline engine in the world. In 1898, Rudolf Diesel, a German inventor and engineer, invented a diesel engine. Internal-combustion engine directly made it possible for Daimler to invent a practical car and for the Wright brothers to invent the first controlled powered plane. At the beginning of the 20^{th} century, American Ford Motor Company developed the assembly-line manufacturing technology. Henceforth, cars were used as vehicles for transportation and travel. Internal-combustion engine replaced steam engine, and became dominant in the fields of automobiles, tractors, planes, ships, engineering machines and war vehicles. With the great development of internal-combustion engine and its application, gasoline and natural gas gradually became major energy sources in the world.

Thirdly, technology of material developed. Machinery manufacturing and railway stimulated the breakthrough of iron and steel technology. In 1856, Henry Bessemer, an English engineer and inventor, invented the steel-making converter. Manufacture of steel with this process was fast and low in energy consumption. Therefore, it spread quickly. During the period from 1856 to 1864, Carl Wilhelm Siemens, a German engineer, and P. Martin, a French engineer, invented a process called "open hearth steelmaking" which was very economical. In the second half of the 19^{th} century, output of steel increased rapidly. The global output of crude steel increased from 510,000 tons in 1870 to 27.83 million tons in 1900. In 1882, S. R. Hadfield, a British metallurgist, developed manganese steel, marking a milestone of the development of alloy steel. In 1886, C. M. Hall, an American inventor and engineer, invented an electrolytic process for producing aluminum. At the end of the 19^{th} century, ferroconcrete played an important role, which marked an epoch in architecture. Thereafter, breakthroughs were made in macromolecule. In 1907, Leo Backland, an American chemist, synthesized a kind of plastic, Bakelite. In 1908, H. Staudinger, a German chemist, invented methyl rubber, which was put into industrial production in 1912.

The second technology revolution produced a large number of new industries, such as electric power and electrical apparatuses, automobiles, and petroleum chemical industries. This technology revolution improved the level and scale of the industries of machinery and smelting, and pushed a mechanical industrial society

into an electric era, in which employment structure and living style had tremendous changes. The Western European countries and the USA not only became major industrial powers but also expanded their influences to Asia and Latin America. Industrial civilization became a mainstream of development in the world.

The Third Technology Revolution

The third technology revolution started in the 1930s and 1940s. After the World War II, new technological innovations took place one after another and developed in a diversified and integral way. The main symbol of the third technology revolution was the development of electronic technology, computer and network information technology. Meanwhile, there were significant breakthroughs in the fields of nuclear energy, space technology, new materials and bio-technology.

The invention of electronic technology and computer started the third technology revolution. Owing to the need of the World War II, the USA successfully developed the first electronic computer in the world, ENIAC. Computers experienced four phases of development: the first generation vacuum tube computer (1946–1959), the second generation transistor computer (1959–1964), the third generation integrated circuit computer (from 1964 to the early 1970s), the forth generation large-scale integration and ultra-large scale integration computers (after the early 1970s). In the 1980s, people began to probe computers of artificial intelligence, biology, photonic integrated circuit and quanta.

The development of computer technology attributed to the inventions of transistor and integrated circuit technology. In 1948, J. Bardeen, an American physicist and electrical engineer, invented transistor, whose special working principle made it possible for electric circuit to integrate and for information to digitize. In 1950 and 1956, transistor televisions and transistor computers came into being one after another. In 1958 and 1959, American engineers, Jack Kilby and Robert Noyce, independently invented integrated circuit. Thereafter, integrate circuits developed from small scale, medium scale, large-scale to ultra-large scale. Integration level increased in one time every 18 months. Meanwhile, its cost decreased in a half, which was close to physical limit of semiconductor.

The advent of the Internet marked another important leap in information technology. Around 1969, ARPANET was built in four universities in the USA, which was the beginning of computer internet. In the early 1980s, with the popularization of personal computer, mutual communication among computers was in great need. This promoted the development of the Internet. In 1993, the USA initiated Information Superhighway Plan, which drew the attention of many countries. It also tremendously changed people's ways of working, learning, shopping and living. Nowadays, the Internet era is transferring into the "Post-IP" era.

Right before the World War II, scientists discovered neutron and the fission chain reaction through experiments, and calculated that uranium fission could produce enormous energy. Governments in Germany, Britain, the USA and the former

Soviet Union successively organized researchers to study uranium fission and its military application. Franklin Roosevelt, the then American president, authorized the Manhattan Engineering District, an atomic bomb building plan, in 1941. In 1942, Enrico Fermi, an Italian physicist, developed the first reactor in the USA. In 1945, the USA developed three A-bombs. The development of nuke, such as A-bombs and H-bombs, exerted a profound influence on the political pattern of the world after the World War II. The nuclear reactor was applied to build nuclear power plant, introducing a new kind of energy source to human beings. The technology of isotope and radiation was widely applied in the fields of industry, agriculture, medicine, scientific research, resources, the environment and public safety.

After aviation stepped into a jet age, space technology grew up. In 1957, Soviet Union succeeded in launching the first man-made satellite, which announced the coming of the space age. In 1961, it also succeeded in manned spacecraft flight, which was the first time for human being to enter into outer space. In 1969, the USA realized Apollo Project, marking a big leap forward in space exploration. In 1971, Soviet Union transported a space station into outer space for the first time. In 1981, the successful flight-test of an American space shuttle marked the beginning of space navigation transport. After navigating for over 30 years, the *Voyager 2*, launched by the USA in 1977, finally arrived at the borderline of solar system in 2008. In 1993, the USA finally built up Global Position System (GPS) after 20 years' efforts and at the cost of 20 billion US dollars. Space technology was applied broadly to civil use, such as communications, navigation and remote sensing. It offered tools for human beings to make use of outer space.

From the end of the 1920s, nickel steel, aluminum alloys, titanium alloys were produced in large quantities. Since the 1930s, large molecule synthetic polymer, such as rubber, plastic and chemical fiber, had developed rapidly. Abionon-metal materials, such as a new type of porcelain, semiconductor materials, glass and cement, had kept developing dramatically. Since the 1950s, researches on rare metal smelting and compound materials have evolved greatly. Some significant events were as follows: the DuPont Company of the USA invented Nylon-66 in 1935, and in the same year, the USA and Germany began to produce chloroethylene plastics. Macromolecule materials kept on replacing natural materials and played a more and more important role. In the 1960s, the world output of synthetic rubber overtook natural rubber for the first time. According to its calculated volume, the world output of plastics was almost equal to that of lumber and cement in the 1970s, and even surpassed that of steels in the early 1980s. Breakthrough in new material realized a big leap forward from natural materials, artificial materials to the creation of new materials, which laid a material base for the third technology revolution.

In this round of technology revolution, except for the technologies mentioned above, there were some breakthroughs made in advanced manufacturing technology, bio-technology and ocean engineering. The third technology revolution enormously improved technological level in various industrial fields. The industrial structure in the world changed dramatically. New industries, represented by the tertiary industry, developed rapidly. More significantly, machinery gradually replaced some mental labor, which pushed society forward into a new era of globalization, knowledge, information and the Internet. Some developed countries stepped into

post-industrial era while others developed into emerging industrial countries through technology innovation. Some developing countries, represented by China and India, are advancing rapidly in the modernization process. The structure of the world is transforming profoundly. A new civilization is forming, which is different from the industrial civilization.

World Modernization Process

Modernization is a profound change of human civilization since the Industrial Revolution in the 18th century, and a complex process of the formation, development, transformation and international interaction of modern civilizations. From the 18th century to the end of the 21st century, the process of world modernization can be divided into two major periods. The first modernization, known as the classical modernization, refers to the transformation from agricultural society to an industrial one, and an agricultural economy to an industrial one, featured by industrialization, urbanization, marketization and democratization. The second modernization, known as the new modernization, refers to the transformation from an industrial society to a knowledge-based one, and an industrial economy to a knowledge-based one, featured by knowledge-intensiveness, informatization, globalization and ecologization. In 2005, there were about 24 countries finalized the first modernization and entered into the second modernization, with about 930 million people in total (see the following table).

The level of modernization of 24 countries in 2005

Countries	Population (million)	First modernization index	Second modernization index
USA	296	100	109
Sweden	9	100	105
Denmark	5	100	102
Japan	128	100	102
Norway	5	100	101
Finland	5	100	101
Australia	20	100	98
Switzerland	7	100	95
The Netherlands	16	100	93
Germany	82	100	93
Belgium	10	100	92
Korea, Rep.	48	100	92
France	61	100	92
Canada	32	100	91
UK	60	100	91
New Zealand	4	100	91

(Continued)

Countries	Population (million)	First modernization index	Second modernization index
Austria	8	100	89
Singapore	4	100	88
Israel	7	100	84
Ireland	4	100	81
Spain	43	100	78
Italy	59	100	78
Portugal	11	100	68
Hungary	10	100	65

Source: Research Group for China Modernization Strategies. 2009. China Modernization Report 2009: Cultural Modernization. Beijing: Beijing University Press

1.2 Signs and Possible Directions of S&T Revolution

Precise prediction of an impending S&T revolution may be difficult, particularly in a certain area. However, it does not mean that there is no way of tracing its sources, which may be rooted either in the transformation of socio-economic development mode caused by modernization and its consequent challenges, or in the transformative breakthroughs caused by the inner contradiction of a knowledge-based system.

- In terms of energy resources, man's excessive consumption of fossil fuels and natural resources to develop its economy should be fundamentally transformed into the use of post-fossil fuels and recycling resources. To achieve this, research breakthroughs must be made to address such basic S&T problems as: mass-energy transformation and its essence, the mechanism of solar energy transformation and photosynthesis, high efficiency hydrogen production and storage, distributed renewable energy with stability and high efficiency, the earth system and its evolution, exploited natural resources in deep earth and continental shelves, high-efficient, clean and circular use of non-renewable energy, the recyclable mechanism and efficient utilization of water resources, bioscience and bionic resource study.

- In terms of information technology, it is likely that, by around 2020, fundamental obstacles may impede the continuous development of almost all the existing information technologies, such as integrated circuits, magnetic disk storage, high performance computers, Internet technology and the like. To achieve this goal, there is a due call for innovation in information science and transformative breakthroughs in information technology, such as: new network theory, new architectures of high-performance network computing,

network security and intelligence, human-computer interaction, language/text/image recognition and transformation, virtual reality, massive data mining and management, new computing technologies based on photoelectron, photon or quantum, self-spinning electron devices, and new generation of chips integrating computing, storage and communication capabilities.

- In terms of advanced materials, possible breakthroughs in future materials science and technology may occur in areas such as: the relationship between materials structures and properties; the evolution laws and mechanisms of materials properties under extreme conditions; *in-situ* real time macro-analysis and characterization of materials performance; precise design and control of materials synthesis and processing; new energy, information and biology materials, nano-materials, and bio-mimetic materials; highly intelligent multi-scale composites; materials with integrated structural and functional properties; life-cycle cost and related controlling technologies; green fabrication process of materials and low-cost high-efficient recycling technologies; continuous processing of materials for near-net-shape forming of components; technologies of material-device integration; and intelligently controlled processing technologies.

- In terms of agriculture, it will enter into the ecological, highly efficient and sustainable development age. It will not only keep its traditional role to guarantee food safety and national economy, but also take the new missions to alleviate global energy crisis, providing diverse demand and creating a better ecological environment. To achieve this, research breakthroughs must be made to deal with such basic S&T problems as: processes and mechanisms for evolutionary biodiversity, basic sciences and methods for effective breeding, interaction mechanism and control methods among nutrients, soil, water, light, temperature and plants, scientific theory for sustainable land use, the response of agriculture to global change, and food and nutritional structural evolution.

- In terms of population, it is expected that the world population will reach to 9 billion in the middle of the 21st century. In such case, we must control population growth, improve population quality, ensure the safety of food and ecology, conquer important human diseases, and take preemptive measures, then develop a cost-effective and generally applicable health assurance system. Therefore, research breakthroughs must be made in such S&T problems as: the effects of nutrition, environment and behaviors on physiological and psychological health; the mechanisms of genetic heredity, variation and their functions; the new technologies for early prediction, diagnosis and preemptive measures, stem cell and regeneration medicine.

- There are some basic science initiatives which are likely to make transformative breakthroughs in the coming decades. In terms of cosmology, the exploration of dark matter, dark energy and antimatter will greatly deepen or even completely change our understanding of the Universe. In terms of the structure of matter, the Control Age is coming into being. Atoms, molecules, even electrons, as constituents of matter, can be manipulated. Thus,

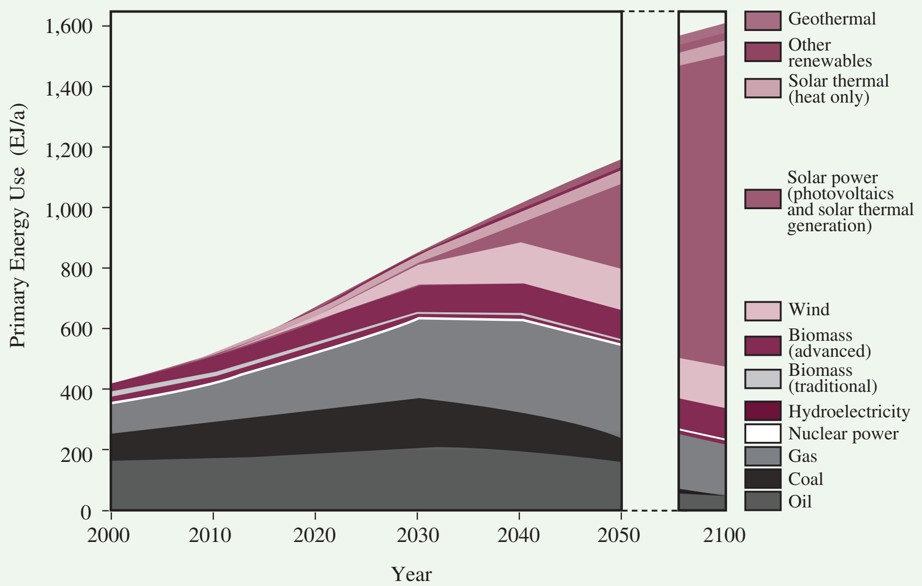
new breakthroughs in high-efficient light/electric/heat energy conversion, photosynthesis, photo-catalysis, energy storage and transfer, information storage, transmission and processing will give rise to new waves of technological and industrial revolution, producing an enormous impact on the human society. In terms of origin and evolution of life, in addition to tools of comparative and evolution genomics for systematic analysis at the molecular level, the emerging "synthetic biology" opens the door of transforming non-living chemical materials to "artificial life". It promises to explore a new avenue to decipher essential/critical puzzles of life via holistic approach. Potentially, synthetic biology will lead to great breakthroughs in life science and bio-technology. It will have revolutionary effects on the improvement of human health, biotechnology-fostered economy, environment protection, and resource preservation. In the research area of brain and cognition, the essence of consciousness is one of the most challenging issues of the modern era, and its breakthroughs will greatly deepen our understanding of nature and human beings, leading to revolutions in information and intelligence science and technology. Its tremendous impacts on the human society are difficult to predict.

Any original scientific innovation in the above areas will open new space in the creation of new scientific paradigms, leading to scientific revolutions. Major technical breakthroughs in any of the above areas will cause new industrial revolution, add new vigor and vitality to world economic growth, give rise to new social transformations, and speed up the modernization and sustainable development process.

Post-Fossil Fuel Era

Energy is an important material base for the survival and development of human beings. In the human history, each revolution of energy resources has promoted the great progress of human civilization. The history of energy use has experienced three periods: traditional bio-energy & firewood period, coal period, and oil period. Now energy use will enter into the post-fossil fuel era, which is dominated by new and renewable energy.

With the eventual exhaustion of traditional fossil energy and the deteriorating environmental pollution caused by fossil energy use, man begins to diversify its energy mix, doing R&D and utilizing nuclear energy, solar energy, wind energy, biomass energy, geothermal energy, ocean energy and etc. These new and renewable energies will eventually supplement and replace the fossil energy, and will become the major energy in the post-fossil energy era.



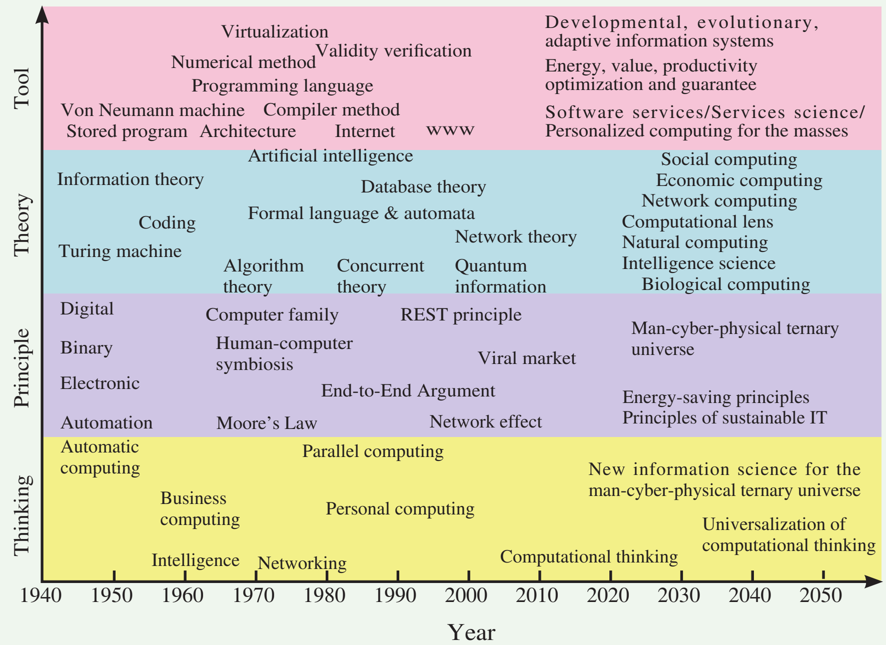
Source: German Advisory Council on Global Change. 2004. World in Transition: Towards Sustainable Energy Systems. Earthscan. London and Sterling,VA

Profound Changes in Information Science and Technology

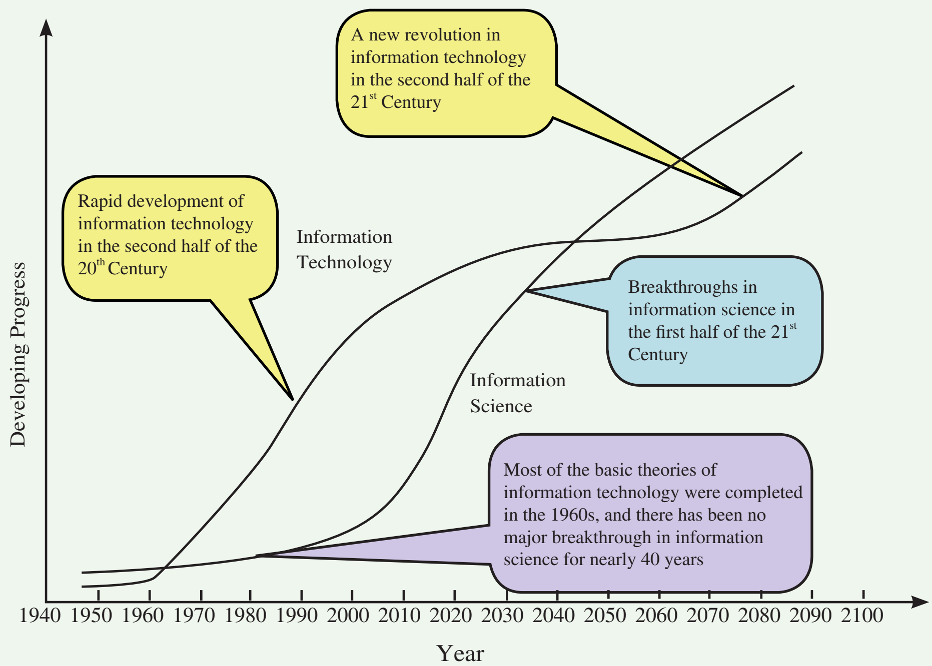
Information science and technology is entering the mass adoption stage worldwide. Information technology beneficial to general public will become a main theme in the coming decades. Increasing attention will be paid to the sustainable development of the information service industry.

In the next 10–15 years, advances in micro-nano electronics technology are expected to follow three paths. 1) The path to continue Moore's law, i.e., to successively miniaturize the feature size of CMOS devices, to increase integration, and to advance system-on-chip (SoC) technology. 2) The path to expand Moore's law, i.e., to realize diverse functions via system-in-package (SiP), not put miniaturization as the only goal. 3) The path of "beyond CMOS", by exploring new principles, new structures and new materials for nano-devices, such as those based on self-spin-electron, single-electron, quantum, molecule, etc.

Information world is changing into a ternary universe comprised of human society, cyberspace, and physical world. The use of information technology will expand from simulating the physical world to embodiment-embedded physical world, from man-machine interaction to planting chips into human bodies. Computing is becoming the link of interaction and convergence among multiple disciplines. The first half of the 21st Century will see the emergence of an information science revolution, featuring high-performance computing and digital simulation as the very fabric of other sciences, to foster new science forms.



Long-term Development Trend of Information Science and Technology



Priority Areas of Information Science to 2050

Main Trends in the Development of Materials Science and Engineering

Materials science and engineering is a discipline which correlates chemical compositions, processing, fabrication, structures and performance of materials and the related application. The main trends in the development of this discipline are: 1) The research and development of nano-materials and nano-structures have been deployed as the most important aspect in the strategy of materials science research. 2) Materials technologies related to information, biology and energy technologies have had rapid development, and attentions paid to these areas are increased. 3) More and more researches are done in optimizing materials properties by combining or integrating different materials, or exploring the new high-performance material systems. 4) The detailed characterization and measurement of material structures, new principles and techniques of ultra-fine assembly processing, have become the prime impetus for the pioneering development in materials science. 5) Greater emphasis has been placed on the development of computational materials science.

Materials Life-cycle Cost and Related Controlling Technologies

The fabrication and application of materials mainly go through the following procedures: natural resources—raw materials—components—parts of an apparatus—a machine system—wastes/resources. Accordingly, the life-cycle cost of materials includes that for developing raw materials, fabrication, machining process, assemblage and integration, detection, maintenance, repair, and recycling. It is the accumulation of the materials consumption in resources, energy, human resources, environment, and other aspects during their service life cycle. With the development of socio-economy and the progress of science and technologies, it will be the inevitable trend to consider the life-cycle cost and analyze related controlling technologies of materials application.

Materials life-cycle cost and related controlling technologies have become important topics with the most universal, urgent, and prospective characteristics in the area of materials science. The restraining factors are: cost from the dependence of resources, cost in the fabrication and processing of materials, cost and efficiency determined by the quality and reliability of materials properties, cost of pollution, and rate of recycling. The key factors of lowering the life-cycle cost can be achieved by breaking through the following core S&T problems: the prediction, design and control of materials service behavior; high efficient recycling of materials; integrating of materials structural characteristics and functional characteristics; technologies of characterizing materials structure as well as analyzing and testing of materials properties.